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Monthly and seasonal assessment of wind energy characteristics at four monitored locations in Liguria region (Italy)

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ABSTRACT

The aim of this paper is to investigate the monthly and seasonal variation of the wind characteristics in term of wind energy potential using the wind speed data collected between 2002 and 2008 for four meteorological stations in Liguria region, in Northwest of Italy, namely Capo Vado, Casoni, Fontana Fresca and Monte Settepani. The results show that Capo Vado is the best site with a monthly mean wind speed between 2.80 and 9.98 m/s at a height of 10 m and a monthly wind power density between 90.71 and 1177.97 W/m^2, while the highest energy produced may be reached in December with a value of 3800 MWh. This study may provide information for developing wind energy sites and planning economical wind turbines capacity for the electricity production in Liguria region, as well as an example of how, deepening the analysis at monthly and seasonal scale, the characteristics of the sites might fall in quite different classes of power density.

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Contents

1. Introduction

Renewable energy has an increasing role in achieving the goals of sustainable development, energy security and environmental protection. Nowadays, it has been recognized as one of the most promising clean energy over the world because of its falling cost, while other renewable energy technologies are becoming more expensive [1]. Wind represents a promising renewable energy source that can meet energy demand in the direct, grid connected modes, as well in stand alone and remote applications [2]. In addition, wind energy systems have made a significant contribution to daily life in some developing countries.

Wind power generation has known a remarkably rapid growth in the past 20 years, and now it is a mature, reliable and efficient technology for electricity production [3]. In addition, in regions with proper wind characteristics, wind energy may already be competitive with coal or nuclear power, especially when the cost of pollution is taken into account in the overall economic evaluation [4].

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Any choice of a wind exploitation site must be based on the preliminary investigation of the average wind velocity and potential, so that the accuracy of the wind resources data analysis is a crucial factor to be undertaken.

The literature is rich with investigations related to the wind power potential and wind assessment. Some key references – according to authors' opinion and with specific reference to the current paper – are quoted hereinafter. An important paper for the aim of this work is by Rehman [5], who realized a detailed analysis of wind speed in terms of energy yield, effect of hub height on energy yield, plant capacity factor, etc. Fyrippis et al. [3] performed a study regarding the wind power potential of Koronos village. They demonstrated that the mean annual wind speed recorded in this area was 7.4 m/s, also they showed that the Weibull distribution could fit their data better than the Rayleigh distribution. In another study, Shata and Hanitsch [6] used the wind data recorded over 23 years for one of the most promising site in Egypt (Hurghada) to calculate the values of the wind speed frequencies. So, the results were used as a tool to make technical and economical evaluation of the electricity generation regarding the choice of suitable wind turbines. Himri et al. [7] used a collection of wind speed over 10 years to assess the economic feasibility of developing wind farms of an installed capacity of 30 MW. A simplified algorithm was developed by Celik [8], to make predictions of the yearly performance of wind energy systems in case of autonomous applications, and on sites where the wind speed are relatively low. Ucar and Balo [9] investigated the wind characteristics collected at six different sites in Turkish territory; according to the authors, the annual average wind speed of those regions at 10 m height is between 5.9 and 8.7 m/s. Conte et al. [10] used a numerical wind flow model, WINDS, developed at the University of Genova, to ascertain the wind resource of Liguria (Italy).

The aim of this paper is to investigate the wind characteristics of four meteorological stations in Liguria region (Northwest Italy), using the wind speed data collected between 2002 and 2008. In this respect, recently, Ouammi et al. [11] analyzed wind data on the same period from 25 stations distributed over Liguria region (that is also including the dataset on which this paper is based). According to kriging maps developed in Ref. [11], different sites show very different wind potential characteristics. In addition, some internal territories on the mountains and some part of the coast in the western side seem to be more promising than others. Specifically, Ouammi et al. [11] demonstrated that Capo Vado, Casoni, Monte Settepani and Fontana Fresca seem to be eligible for energy production.

This work can be taken into account as a further development of Ref. [11], taking into account the need of stakeholders and regional planners to enhance the information on the possible exploitation of the four sites for energy production, mostly in terms of monthly and seasonal variations of wind characteristics. In general, this study aims to provide information for further developing the implementation of wind energy plants, planning the capacity of proper wind turbines capacity that should be used for the production of the electricity, and evaluating how monthly and seasonal shortage might be supplied using additional renewable energy sources.

2. Wind speed data

The knowledge of the wind speed regimes is a fundamental factor to evaluate the wind potential over a territory. The accuracy of this evaluation is crucial as the provided power is function of the cube of the wind speed. In this paper, data from four stations distributed over Liguria region have been analyzed. The geographical coordinates of these meteorological stations are given in Table 1. The data used in this current study have been monitored in the following periods: Casoni (2002–2008), Monte Settepani, Fontana Fresca (2004–2008), and Capo Vado (2006–2008).

Table 1
Geographical wind speed observations.

Station	Elevation (m)	Latitude N	Longitude E
Capo Vado	170	44.2583	8.4425
Casoni	800	44.5272	9.3086
Fontana Fresca	743	44.4022	9.0936
Monte Settepani	1375	44.2430	8.1966

The data have been here used to evaluate, the monthly and seasonal variations as regards average wind speed, the vertical profile of the wind speed and the assessment of wind power potential.

3. Wind analysis model

The computation of the wind speed probability distribution function (PDF) constitutes the first fundamental step to assess the wind energy potential, since it can effectively determine the performance of wind energy systems for a given location and time [12,13]. Several PDFs have been proposed in the literature to represent the frequencies of the wind speed. The Weibull with its two characteristic parameters is the most commonly used and different estimation methods can be used for its identification [13].

The general form of the Weibull PDF is:

$$f(v) = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1}\exp\left(-\left(\frac{v}{c}\right)^{k}\right) \tag{1}$$

where $f(v)$ is the probability of observing wind speed v, k is the dimensionless Weibull shape parameter, and c is the Weibull scale parameter.

According to the measurements of wind speed at a specific site, it is necessary to use estimation methods to derive parameters k and c on the basis of the known data v. Common estimation methods can be applied: the standard deviation method (SD), the maximum likelihood method (MLM), or the least squares method (LSM). In this study, the SD method has been used, so that the two parameters of Weibull PDF, k and c can be related to the mean wind speed V_m and standard deviation σ by [14,15]:

$$V_m = \int_0^\infty v\, f(v)\, dv = \int_0^\infty v\left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1} e^{-(v/c)^K}\, dv = c\Gamma\left(1+\frac{1}{k}\right) \tag{2}$$

where

$$\Gamma(y) = \int_0^\infty e^{-x}x^{y-1}\, dx \tag{3}$$

$$k = \left(\frac{\sigma}{V_m}\right)^{-1.086} \tag{4}$$

$$c = \frac{V_m}{\Gamma(1+(1/k))} \tag{5}$$

3.1. Extrapolation of data at hub height

The wind speed data are collected at a height H_{data} [m] that is different from the height of the hub. So, it is necessary to represent the relation among wind speed v_{hub} [m/s] at hub height H_{hub} [m], the wind speed v_{data} [m/s] at H_{data}, and the surface roughness length z_0 [m]. In this work, a relation proposed in Refs. [16,17], is used, namely:

$$v_{hub} = v_{data}\frac{\ln(H_{hub}/z_0)}{\ln(H_{data}/z_0)} \tag{6}$$

3.2. Wind power density

The power of the wind that flows at speed v through the blade sweep area A [m^2] increases as the cubic of its velocity and is given by [18]:

$$P(v) = \frac{1}{2}\rho A v^3 \tag{7}$$

where ρ [kg/m^3] is the density of air.

The wind power density of a site based on Weibull's probability density function can be expressed as follows [18]:

$$P = \int_0^\infty P(v)\ f(v)\,dv = \frac{1}{2}A\rho c^3 \Gamma\left(\frac{k+3}{k}\right) \tag{8}$$

3.3. Classes of wind power density

The Battelle-Pacific Northwest Laboratory (PNL) developed a wind power density classification scheme to classify the wind resources. The Battelle-PNL classification is a numerical one which includes rankings from Wind Power Class 1 (lowest) to Wind Power Class 7 (highest). Each class represents a range of wind power density (W/m^2) or a range of equivalent mean wind speeds at specified heights above ground level [19]. Class 4 or greater are considered to be suitable for most wind turbine applications. Class 3 areas are suitable for wind energy development using taller wind turbine towers. Class 2 areas are considered marginal for wind power development and Class 1 areas are unsuitable [19]. More description of the Battelle-PNL classification can be found in Ref. [19].

As determined by Ouammi et al. [11], taking into account a statistical analysis on the whole year, the wind power densities of Capo Vado, Casoni, Fontana Fresca and Monte Settepani are equal, respectively, to 487.7, 332.5, 206.5 and 203 W/m^2. Consequently, Capo Vado appears to have potential wind resources as Class 7, Casoni is classified as Class 6 and both Fontana Fresca and Monte Settepani are classified as wind power Class 4.

4. Modelling the wind power plant and its performance

The estimation of the exploitable energy requires the definition of the performances of the wind power plant (WPP) system. The WPP simplified model which is taken into account in this work is related to a horizontal axis wind turbine equipped with a gearbox. So, the WPP is supposed to consist of three main components: the rotor R, the gearbox GB, and the generator G.

The site will be characterised by a wind speed v [m/s] with a statistical distribution function $f(v)$, equipped with a WPP whose efficiency is C_{WPP} and with a rotor sweeping a surface A [m^2], working in a range of wind speed $v \in [v_i, v_f]$, where v_i [m/s] is the cut-in wind speed, and v_f [m/s] is the cut-off wind speed.

Under the above mentioned hypothesis, the electric energy E_{wt} [kWh] which can be produced per time period T is given by [20]:

$$E_{\mathrm{wt}} = \frac{T}{1000}\frac{\rho}{2}A\int_{v_i}^{v_f} v^3\ f(v)_{\mathrm{hub}}\,C_{\mathrm{WPP}}(v)\,dv \tag{9}$$

where T is the number of hours, ρ [kg/m^3] is the air density, $f(v)_{\mathrm{hub}}$ is the Weibull PDF at the height of the hub and A [m^2] is the area swept by the WPP blades.

The WPP performance coefficient of the plant system, $c_{\mathrm{WPP}}(v)$, is made by three related components, which are also dependent on the wind speed v [20]:

$$c_{\mathrm{WPP}}(v) = c_{\mathrm{P}}(v)\,\eta_{\mathrm{GB}}(v)\,\eta_{\mathrm{G}}(v) \tag{10}$$

with c_{P} the power coefficient, η_{GB} the gearbox efficiency and η_{G} the generator efficiency.

5. Results

In this study, a WPP with the following geometric and technical characteristics has been considered to assess the energy output: rated power 1500 kW; cut-in wind speed of 4 m/s, rated wind speed of 14 m/s, cut-off wind speed of 20 m/s, survival wind speed of 52.5 m/s; 3 blades; diameter 82 m; hub height 76 m; and swept area of 5281 m^2. Furthermore the power coefficient, gearbox efficiency and generator efficiency have been supposed equal, respectively, to 0.45, 0.96 and 0.96.

The wind speed data of the four locations (Capo Vado, Casoni, Fontana Fresca and Monte Settepani) have been analyzed taking into account the monthly and seasonal variations. The monthly variation of Weibull parameters (k and c) and the mean monthly wind speed at 10 and 76 m above the ground level are listed in Tables 2–5.

For Capo Vado site (Table 2), it can be observed that the maximum value of the monthly mean wind speed at 10 m is 9.98 m/s in December and a minimum value of 2.80 m/s occurs in April, while at the hub height the monthly wind speed varies between 3.73 and 13.46 m/s. Furthermore, Weibull shape parameter k varies between 0.95 and 1.94, while scale parameter c between 2.73 and 11.25 m/s.

For Casoni site (Table 3), the maximum value of the monthly wind speed at 10 m is equal to 7.86 m/s in December, whereas the minimum one is equal to 4.41 m/s in August. At the hub height, the monthly wind speed varies between 5.95 and 10.61 m/s. The shape parameter k takes values between 1.30 and 2.03 while the scale parameter c between 4.97 and 8.62 m/s.

Table 2
Monthly variations of the mean wind speed and Weibull parameters for Capo Vado site.

Month	c (m/s)	k	Mean wind speed (m/s) 10 (m)	Mean wind speed (m/s) 76 (m)	Power density (W/m^2)
January	5.91	1.45	5.36	7.24	265.52
February	7.60	1.64	6.80	9.17	453.93
March	7.80	1.53	7.02	9.47	550.20
April	2.73	0.95	2.80	3.78	90.71
May	5.06	1.36	4.63	6.24	187.71
June	5.29	1.58	4.75	6.41	162.55
July	4.95	1.53	4.46	6.01	140.21
August	5.78	1.82	5.14	6.93	172.04
September	6.42	1.49	5.80	7.83	321.06
October	9.22	1.89	8.19	11.05	666.03
November	9.06	1.62	8.11	10.95	783.07
December	11.25	1.94	9.98	13.46	1177.97

Table 3
Monthly variations of the mean wind speed and Weibull parameters for Casoni site.

Month	c (m/s)	k	Mean wind speed (m/s) 10 (m)	Mean wind speed (m/s) 76 (m)	Power density (W/m^2)
January	7.50	1.36	6.87	9.27	620.14
February	7.15	1.63	6.40	8.63	381.04
March	7.05	1.46	6.38	8.61	441.65
April	6.21	1.30	5.73	7.73	384.75
May	5.42	2.03	4.80	6.48	125.21
June	5.53	1.89	4.91	6.62	143.73
July	5.13	1.86	4.56	6.15	117.11
August	4.97	1.83	4.41	5.95	108.32
September	5.61	1.54	5.05	6.81	202.53
October	6.51	1.48	5.88	7.94	339.62
November	7.04	1.44	6.39	8.62	452.95
December	8.62	1.39	7.86	10.61	894.86

Table 4
Monthly variations of the mean wind speed and Weibull parameters for Fontana Fresca site.

Month	c (m/s)	k	Mean wind speed (m/s) 10 (m)	Mean wind speed (m/s) 76 (m)	Power density (W/m^2)
January	6.65	1.73	5.93	7.99	279.36
February	5.92	1.47	5.36	7.22	257.13
March	6.61	1.68	5.90	7.96	286.11
April	4.52	1.53	4.07	5.49	107.03
May	5.10	1.82	4.53	6.12	117.81
June	5.15	1.92	4.57	6.17	114.48
July	4.15	1.76	3.69	4.98	66.13
August	4.86	1.68	4.34	5.86	113.80
September	4.52	1.41	4.11	5.55	124.44
October	5.64	1.36	5.17	6.97	261.95
November	6.13	1.50	5.53	7.46	275.45
December	7.46	1.43	6.78	9.15	547.46

Table 5
Monthly variations of the mean wind speed and Weibull parameters for Monte Settepani site.

Month	c (m/s)	k	Mean wind speed (m/s) 10 (m)	Mean wind speed (m/s) 76 (m)	Power density (W/m^2)
January	7.04	2.26	6.24	8.41	248.60
February	7.58	2.16	6.72	9.06	322.22
March	6.30	1.90	5.59	7.55	212.04
April	6.28	2.45	5.57	7.51	166.26
May	5.81	2.34	5.15	6.95	136.11
June	5.61	2.43	4.97	6.71	118.76
July	5.30	2.25	4.69	6.33	106.21
August	5.70	2.11	5.05	6.81	140.18
September	5.88	2.07	5.21	7.03	157.08
October	7.12	1.95	6.32	8.52	296.46
November	7.07	1.95	6.27	8.46	289.53
December	7.83	2.32	6.94	9.36	334.71

Results of Fontana Fresca location (Table 4) reveals that at 10 m, a value of 6.78 m/s is observed as a maximum monthly wind speed in December and a minimum value of 3.69 m/s in June, furthermore at the hub height, the monthly wind speed is ranging between 4.98 and 9.15 m/s. The shape parameter k varies between 1.36 and 1.92 while the scale parameter c between 4.15 and 7.46 m/s.

As concern Monte Settepani (Table 5), it appears that December is still the month that gives the maximum value of the wind speed, and which attains 6.94 m/s at 10 m. On the other hand, the wind speed reaches its minimum limit in July (4.69 m/s). At the hub height, the monthly wind speeds rang between 6.33 and 9.36 m/s. The shape parameter k takes a value between 1.90 and 2.45, while the scale parameter c between 5.30 and 7.83 m/s.

To sum up, a maximum value of the mean wind speed at 10 m is obtained at Capo Vado as 9.98 m/s in December. Furthermore, the Weibull parameter k varies between 0.95 and 2.45 with a minimum at Capo Vado in April and a maximum at Monte Settepani also in April. The parameter c varies between 2.73 and 11.25 m/s, thus for a maximum and minimum values observed at Capo Vado in December and April, respectively.

In addition, the knowledge of the wind direction is an essential task to carry out in order to make a better understanding regarding the planning of the wind turbine installations. The wind direction frequencies for the four locations are displayed in Fig. 1. The wind directions show a quiet similar behaviour. But for Fontana Fresca, all the other locations (Capo Vado, Casoni and Monte Settepani) exhibit a distribution between NNE to NNW pattern. For Capo Vado, the predominant wind direction is the North with a value of 37%, while for Casoni and Monte Settepani; it is, respectively, NNE and NNW with 31 and 41%. An opposite tendency is observed at Fontana Fresca site, where the predominant direction is the South with 22%.

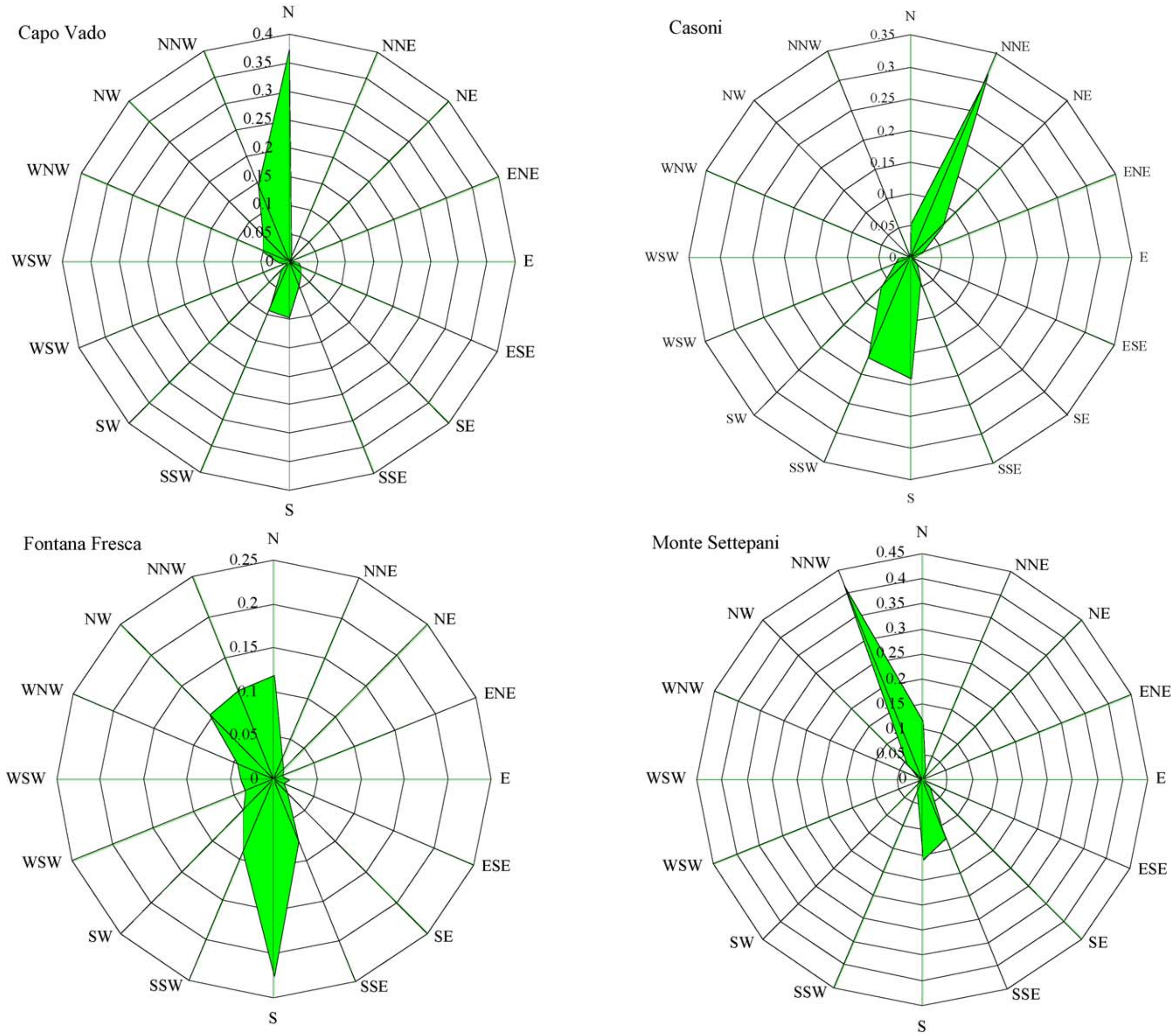

Fig. 1. Annual wind direction frequencies at the four locations.

The estimation of the mean wind speed over a site is not a final step to assess the available wind potential in the considered site. Moreover, the value of the power density is an important parameter that can provide complementary information regarding the choice of suitable site, as well as an immediate classification of the site. For this main reason, the wind power density available at the four locations has been computed. Fig. 2 reveals the monthly variation of mean wind power density at different heights for the four selected stations. It can be recognized that all the four stations (Capo Vado, Casoni, Fontana Fresca and Monte Settepani) exhibit the same tendency as regards the highest monthly mean wind power density and which occurs in December. Whereas, once it comes to the minimum wind power density, the rate of variation is not the same; the occurrence of the minimum differs from one site to the other. At 10 m elevation, this minimum is reached in August at Casoni site with a value of 108.32 W/m^2, and for Capo Vado in April with a value of 90.71 W/m^2, while for the two other sites Fontana Fresca and Monte Settepani, their minimum values occur in July with values equal, respectively, to 66.13 and 106.21 W/m^2. Comparing the trend of the four wind power density in Fig. 2, the wind power density has its maximum value in December for Capo Vado with 1177.97 W/m^2 at 10 m and 2411 W/m^2 at the hub height (76 m).

The seasonal wind characteristics for all the stations are shown in Table 6. It is observed that the highest value of the mean wind speed and the mean wind power density for all locations are observed in the Autumn season which coincides with the increased demand of energy. It is also apparent from the same table that Capo Vado location is the windy site, at which the maximum seasonal mean wind speed is about 8.76 m/s (at height of 10 m) observed in the Autumn season, while the minimum of 4.06 m/s in Spring, whereas the seasonal mean power density varies between 134.64 and 872.87 W/m^2 reached, respectively, in Spring and Autumn seasons. At the hub height (76 m), the seasonal mean wind speed occurred between 5.48 and 11.81 m/s. The obtained results for the other locations are reported in details in Table 6.

The seasonal variation of the wind speed can help in forecasting the future trend of wind projects. Due to the randomly behaviour of the wind speed and also its variation over the time, it is more practical to represent its behaviour using a probability function. The comparison between the actual seasonal data and the estimated seasonal Weibull frequency distributions of wind speed of the four locations are shown in Fig. 3. It can be seen that the Weibull distributions demonstrate a good fit. Furthermore, it is observed for Capo Vado and Casoni, that the wind speed covers the

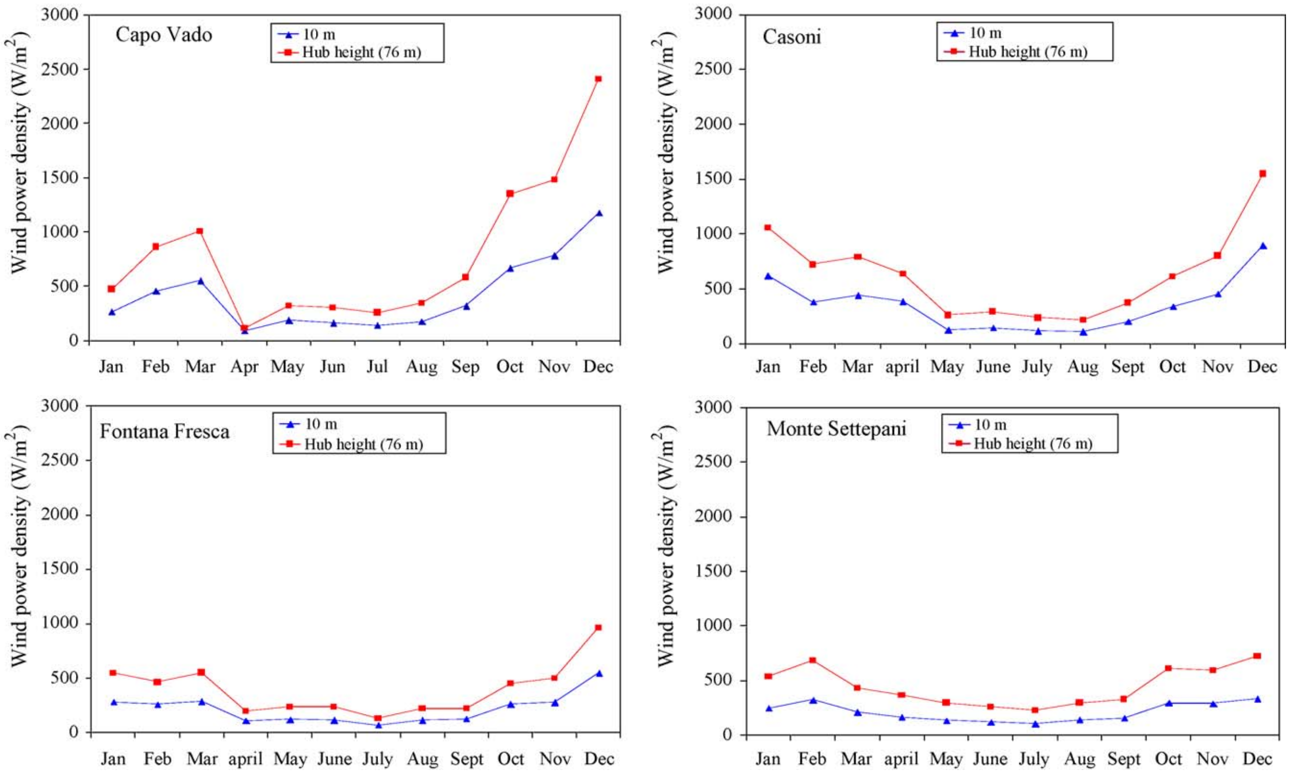

Fig. 2. Monthly variation of wind power density for the four locations.

large range of variation in Winter and Autumn seasons, and which reaches [0–20 m/s], whereas in Spring and Summer the higher range limit does not exceed 15 m/s. For Fontana Fresca and Monte Settepani, the wind speed covers the large range of variation in Winter and Autumn which equal to [0–15 m/s]. In Spring and Summer the higher range limit does not exceed 10 m/s. Results of wind availability in Capo Vado site show that the wind speed is above 3 m/s, respectively, in Autumn, Winter, Spring and Summer with 82, 68, 49 and 63% of the time, so the wind power plant can produce energy for 82, 68, 49 and 63% of the times, respectively, in Autumn, Winter, Spring and Summer. The higher percentage of wind availability in Winter occurs at Casoni and Fontana Fresca, respectively, with 70 and 67%, and at Monte Settepani in Autumn with 79%.

The histograms of the monthly variation of the mean wind energy produced by the WPP and the available wind energy in the swept rotor area for the four locations are shown in Fig. 4. It is important to underline that, for the whole four locations, the highest energy produced by WPP can be reached in December, respectively, with 3800, 2439, 1519, and 1146 MWh. Further seasonal assessments of the available and produced energy are reported in Fig. 5. For all sites, the produced energy by the WPP

Table 6
Seasonal wind characteristics for all the stations.

Season	c (m/s)	k	Mean wind speed (m/s) 10 (m)	Mean wind speed (m/s) 76 (m)	Power density (W/m^2)
Capo Vado					
Winter	7.09	1.51	6.39	8.63	422.47
Spring	4.41	1.32	4.06	5.48	134.64
Summer	5.71	1.56	5.13	6.92	208.45
Autumn	9.84	1.78	8.76	11.81	872.87
Casoni					
Winter	7.23	1.46	6.55	8.84	477.06
Spring	5.73	1.58	5.15	6.94	207.00
Summer	5.24	1.69	4.67	6.30	140.88
Autumn	7.36	1.39	6.71	9.06	555.13
Fontana Fresca					
Winter	6.40	1.62	5.73	7.73	274.30
Spring	4.93	1.74	4.39	5.93	113.15
Summer	4.51	1.58	4.05	5.46	100.46
Autumn	6.39	1.40	5.83	7.86	359.11
Monte Settepani					
Winter	6.98	2.08	6.18	8.34	260.94
Spring	5.90	2.39	5.23	7.06	140.25
Summer	5.63	2.12	4.98	6.72	134.16
Autumn	7.35	2.06	6.51	8.78	307.17

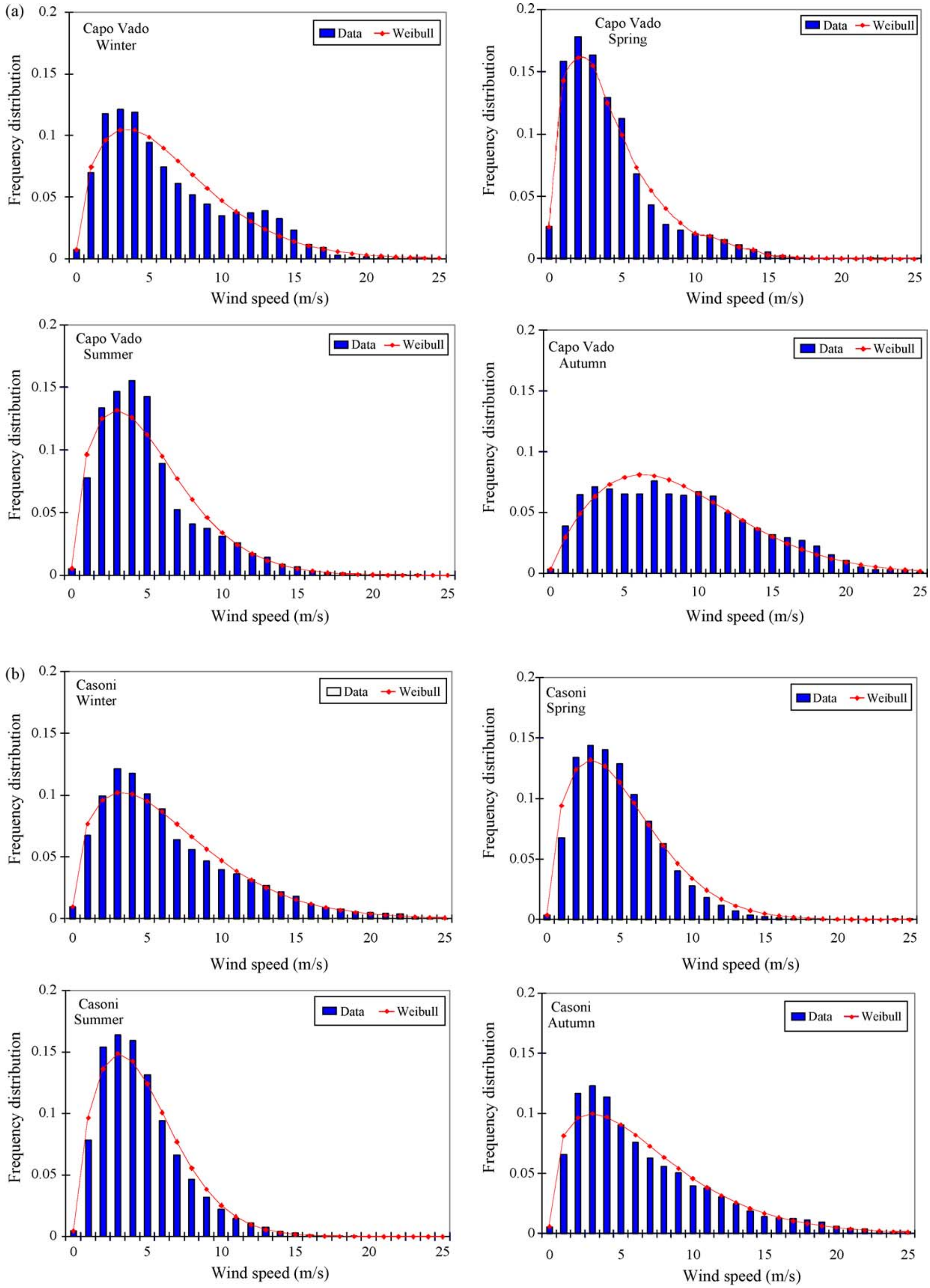

Fig. 3. Seasonal histograms of the wind speed.

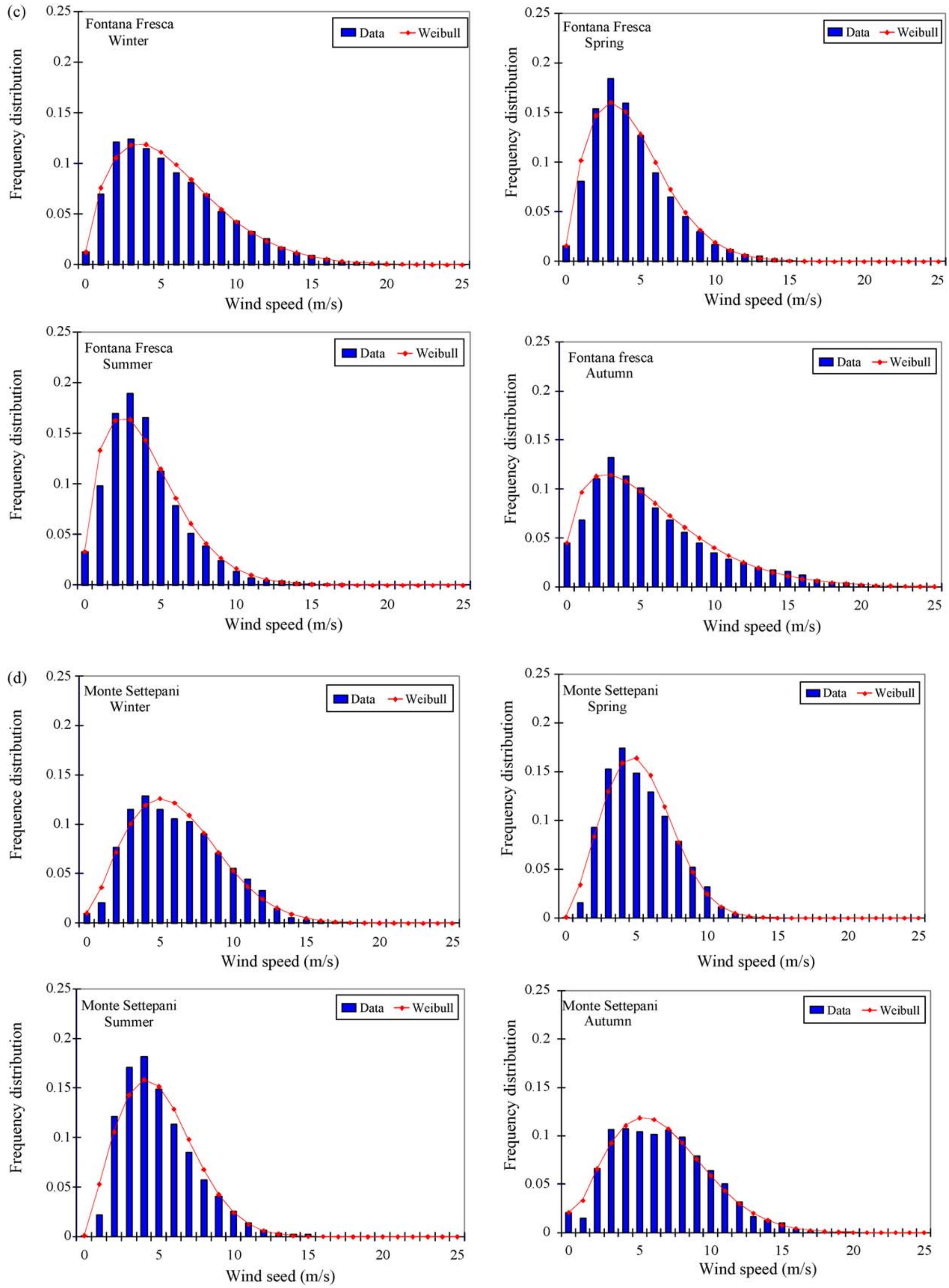

Fig. 3. (*Continued*).

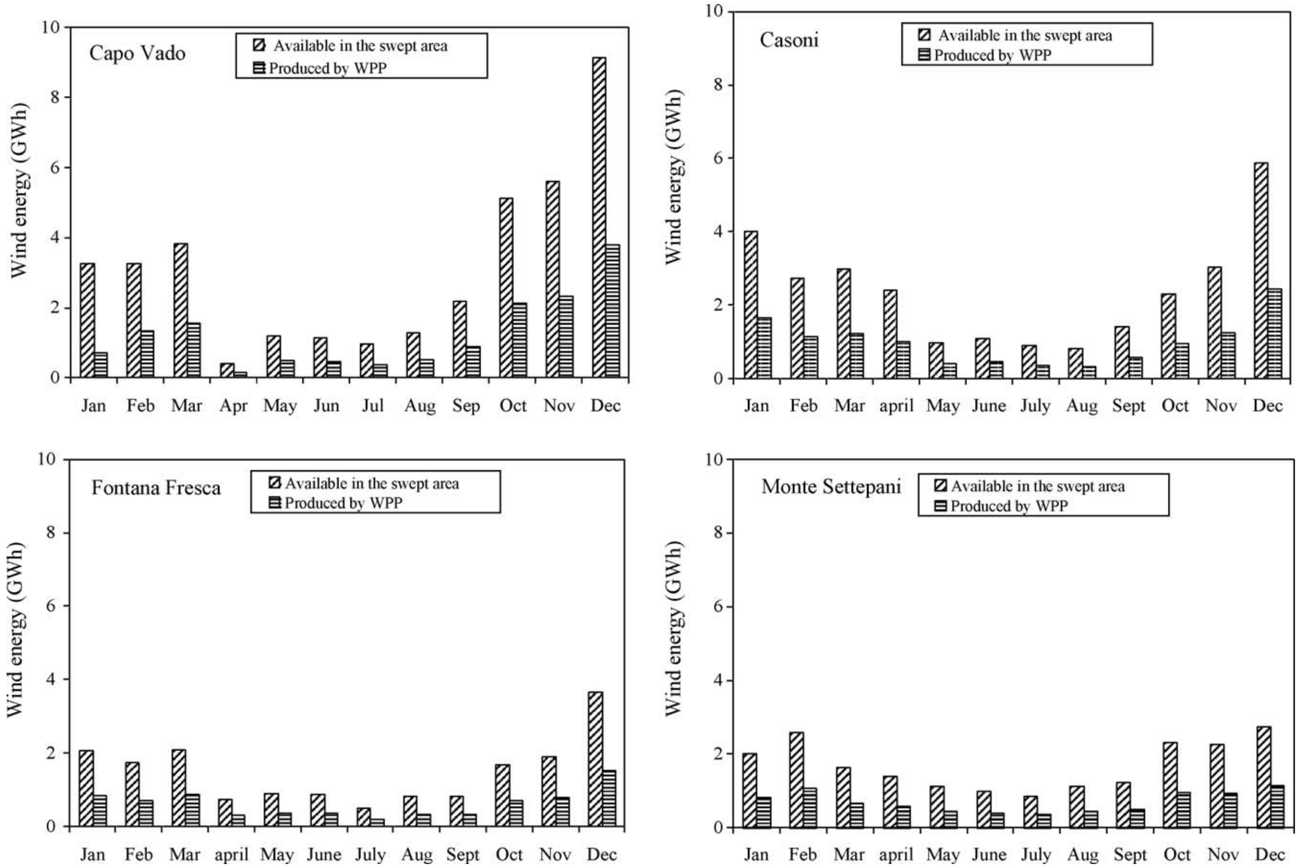

Fig. 4. Histograms of the monthly of the mean wind energy produced by the wind power plant versus the available wind energy in the swept rotor area for the four locations.

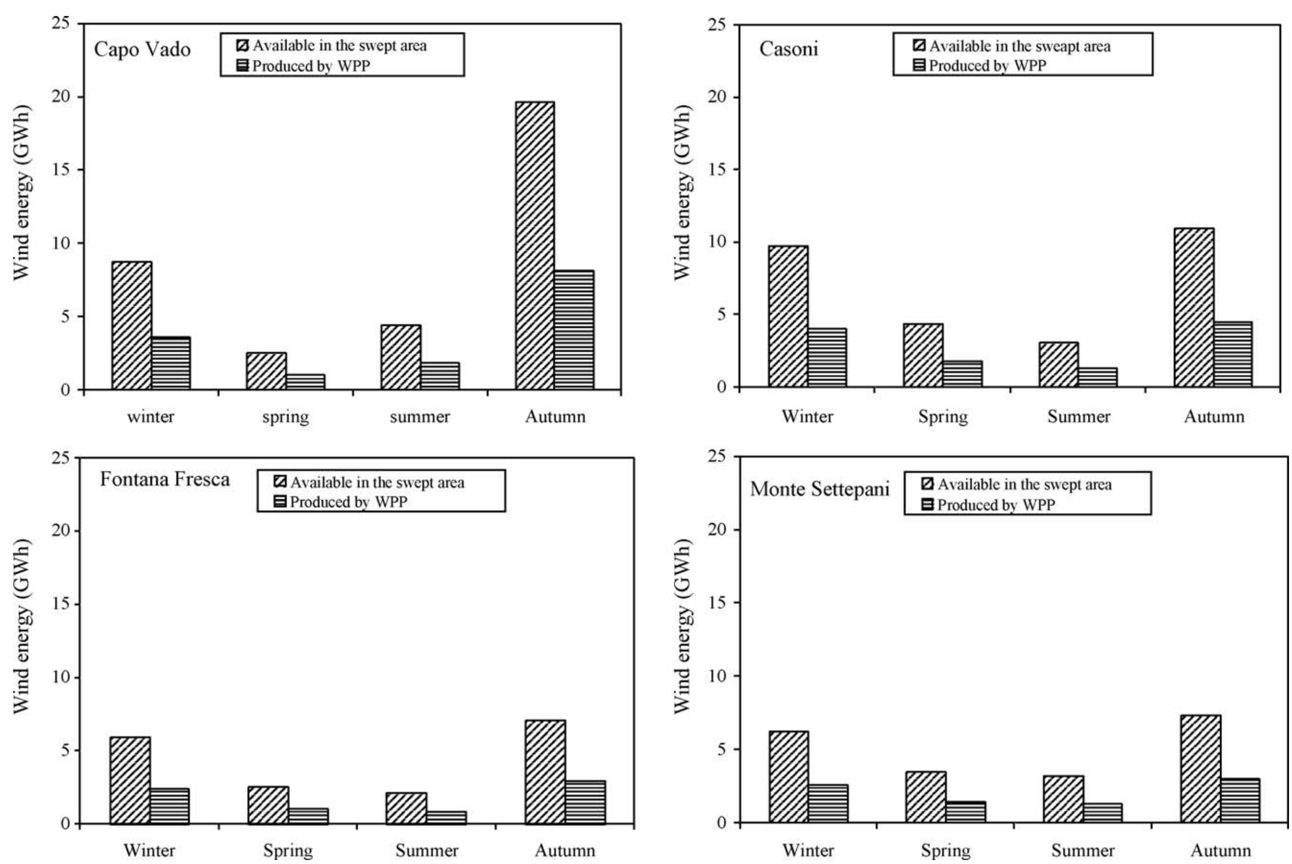

Fig. 5. Seasonal assessment of the available and produced wind energy for the four locations.

shows a large variation from season to season, in addition, the highest production values for all stations occur in Autumn season with 8164, 4544, 2951 and 3039 MWh, respectively, at Capo Vado, Casoni, Fontana Fresca and Monte Settepani.

6. Conclusion and future directions

The monthly and seasonal wind data analysis has been carried out to investigate wind characteristics and WPP production during a period between 2002 and 2008 in the four locations of Liguria region. The monthly and seasonal wind speed distribution, wind power densities and wind direction are determined for the four locations in order to provide information of wind resources, further assessment of the monthly and seasonal wind energy available in each site and the energy output of the WPP have been done. It is believed that Capo Vado is the best site with a monthly mean wind speed determined between 2.80 and 9.98 m/s in December at a height of 10 m and a monthly wind power density between 90.71 and 1177.97 W/m^2 while the highest energy produced by WPP was reached in December with 3800 MWh.

As a result of the Battelle-PNL classification made in Section 3.3 – Capo Vado Class 7, Casoni Class 6, Fontana Fresca and Monte Settepani Class 4 – all the four sites are considered to be suitable for most wind turbine applications taking into account data on the whole year. On the other hand, for example, Capo Vado dramatically falls in Class 1 if data limited to the month of April are taken into account and in Class 7 if limited to the months February, March, October, November and December. This fact should reflect the inadequacy of Battelle-PNL classification on regions with a complex orography and variable wind characteristics as Liguria region, and, in general, as many others Mediterranean countries.

The seasonal variation of these sites should reflect the need of adopting proper strategies to adapt the wind exploitable energy to the demand. These could be done according to two main – not alternative – strategies: hybridizing the production with the contribution of some other renewable energies; storing energy to feed future demand with the aim to avoid shortage. As regards the former option, for the sites investigated in this work, solar energy should be a promising option, since sun irradiation reaches high values just in the months and seasons where wind seems to have lower energy exploitation. As regards the latter option, hydrogen might be a challenging way to store energy, specifically if coupled with automotive hydrogen fuel future demand. For example, as a rough estimation, for the site of Capo Vado, the estimated hydrogen gas mass that can be produced using an electrolyser characterised by an efficiency of 0.9 is about 65 tones in December (2166 kg/day) which is equivalent to 2558 MWh of hydrogen energy production and 3 tones in April which is equivalent to 117 MWh of hydrogen energy production. In this respect, proper strategies should be studied to couple the storage of hydrogen for household and industrial energy consumption and as a fuel for transport vehicles. From an automotive perspective, as a kilogram of hydrogen is roughly equivalent to a gallon of gasoline in energy content, assuming a 6 kg/fill average per day for a car, the 2166 kg/day would fill approximately 360 cars per day, For a hydrogen vehicle with internal combustion engine fuel consumption is about 0.60 kWh/km as reported by Ref. [21], thus, the hydrogen energy production in December for Capo Vado site is more than 4×10^6 km.

As a future development, the authors wish to work both to proper energy classification methods of the sites from a wind exploitation perspective, which take into account the monthly and seasonal variations. Another interesting and challenging research direction is on optimal strategies to storage energy from wind exploitation using the hydrogen as energy vector.

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